Jet Propulsion Laboratory
California Institute of Technology

A Possible Technology Path Towards an Exo-Earth Imaging and Characterization Mission

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California Institute of Technology

SPIE

San Diego

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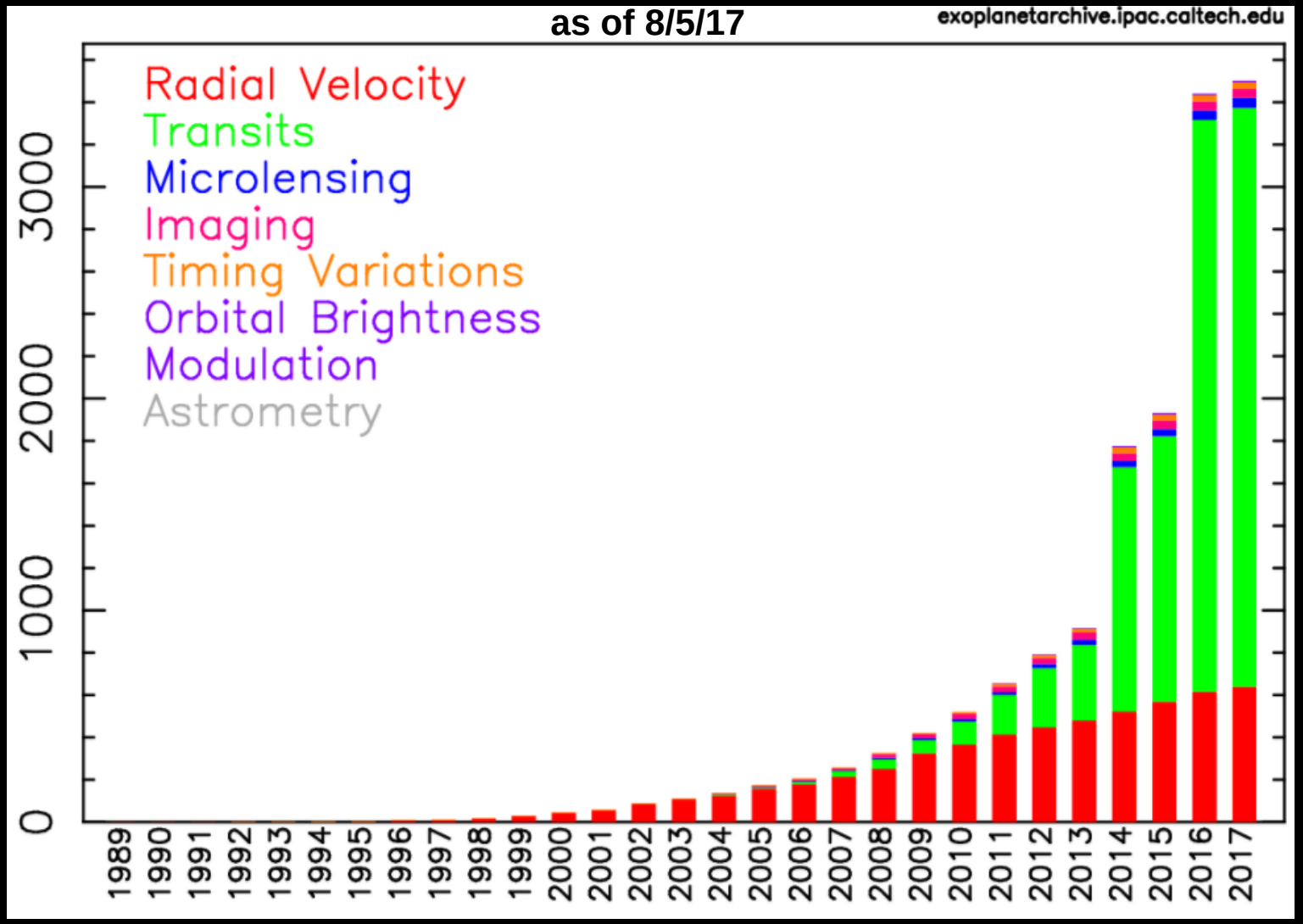
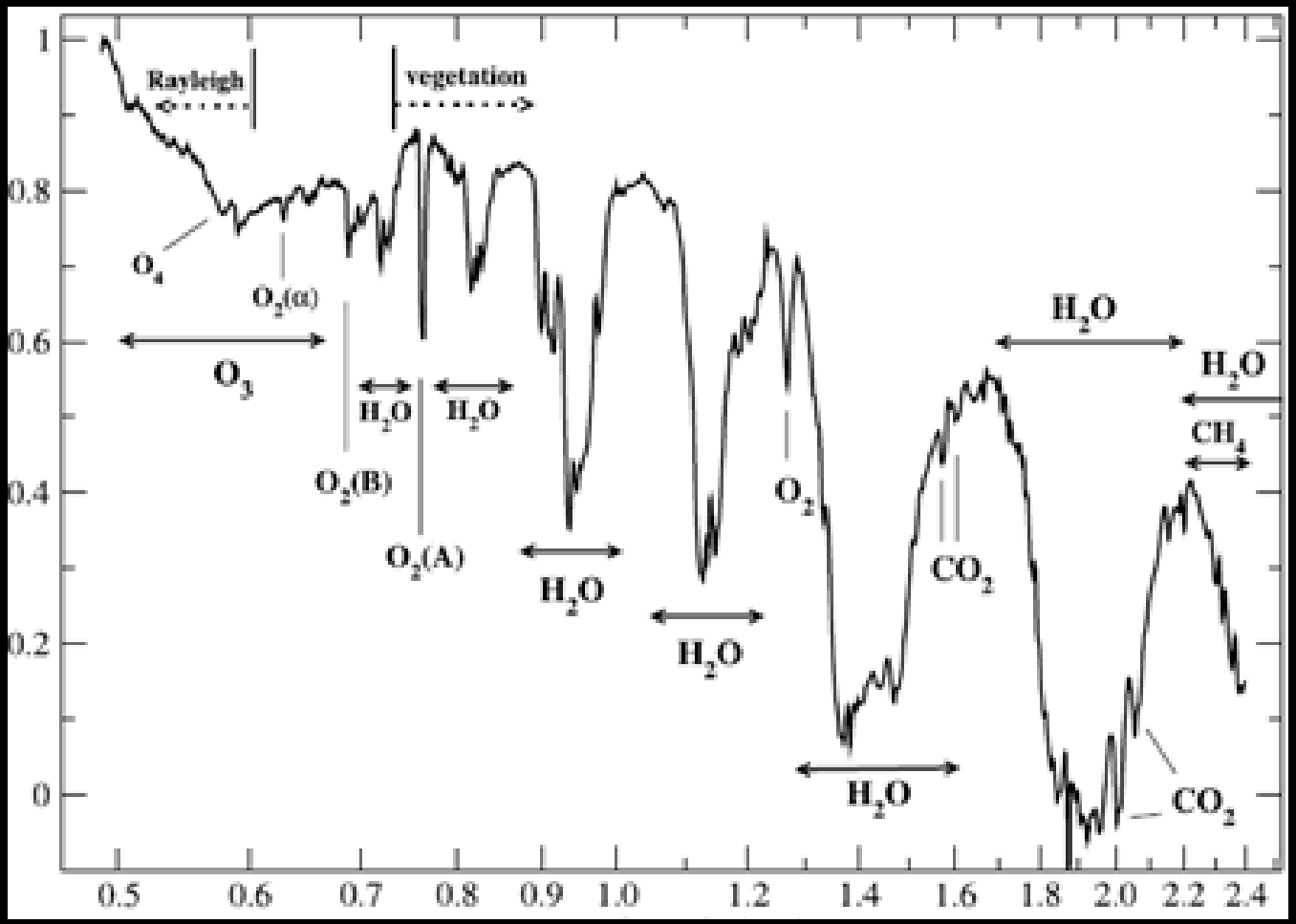
Pre-Decisional Information -- For Planning and Discussion.Purposes Only

3502 Confirmed Exoplanets

… and counting



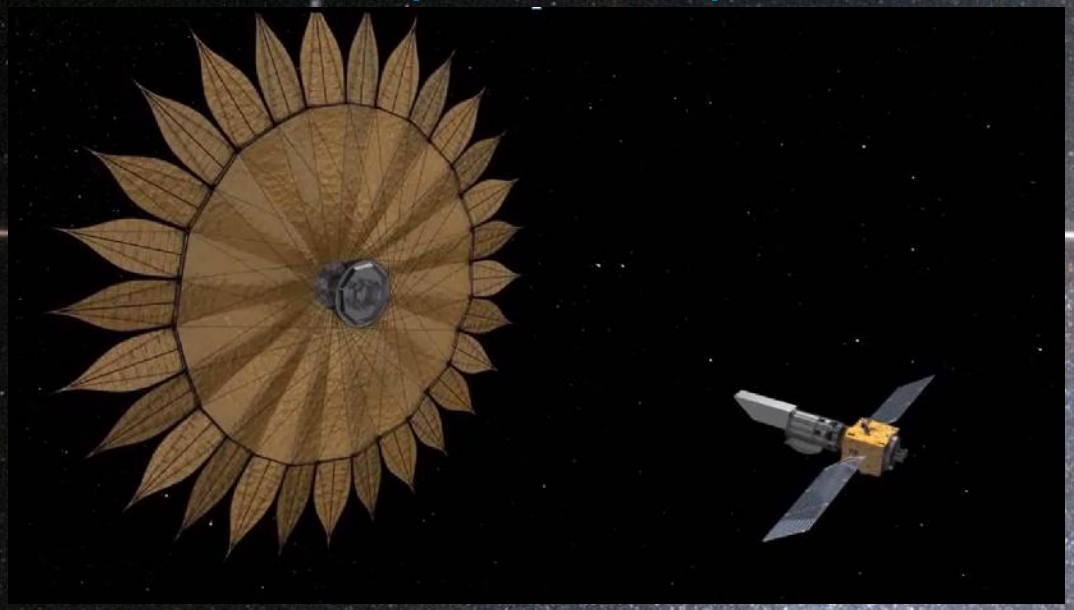
The Evidence for Life on Exoplanets

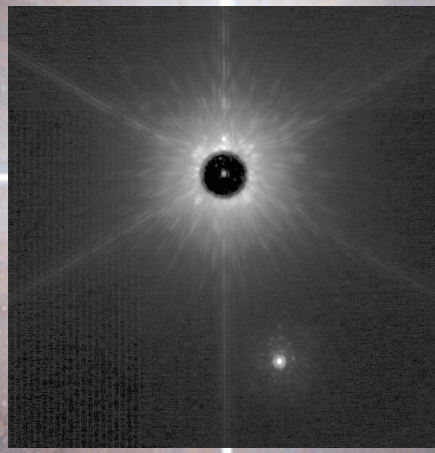


Turnbull *et al.* 2006

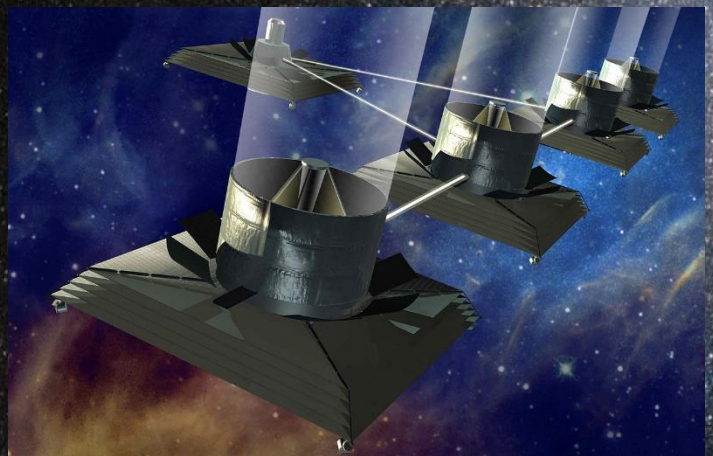
Starlight Suppression is the Key Technology in the Search for Earth-Size Exoplanets and Life

External Occulter (Starshade)

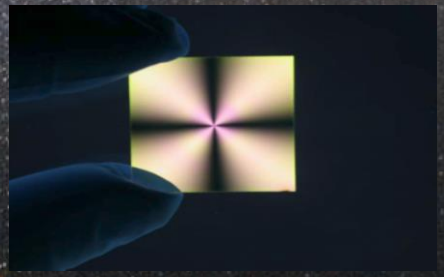


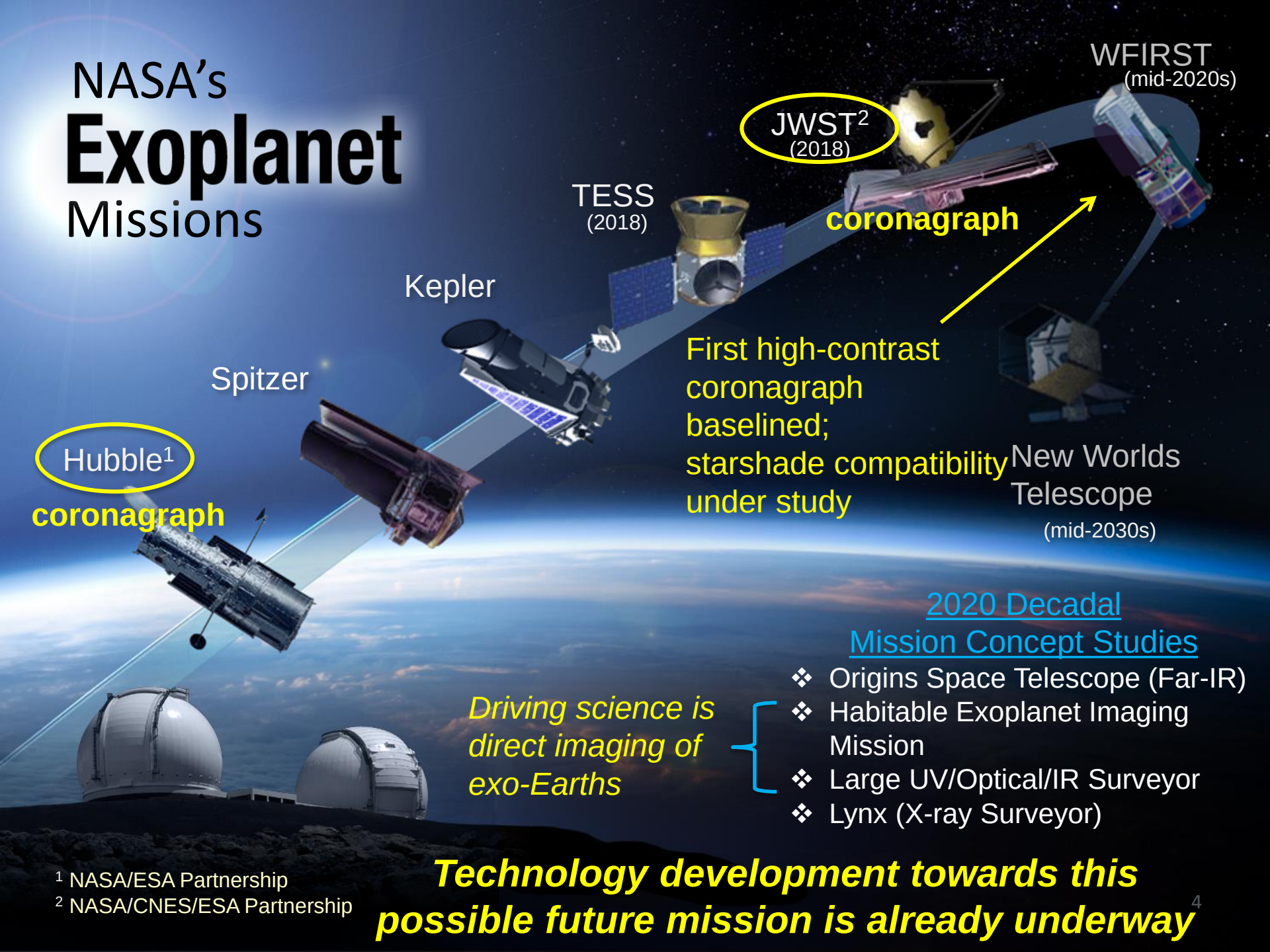


Nulling Interferometry

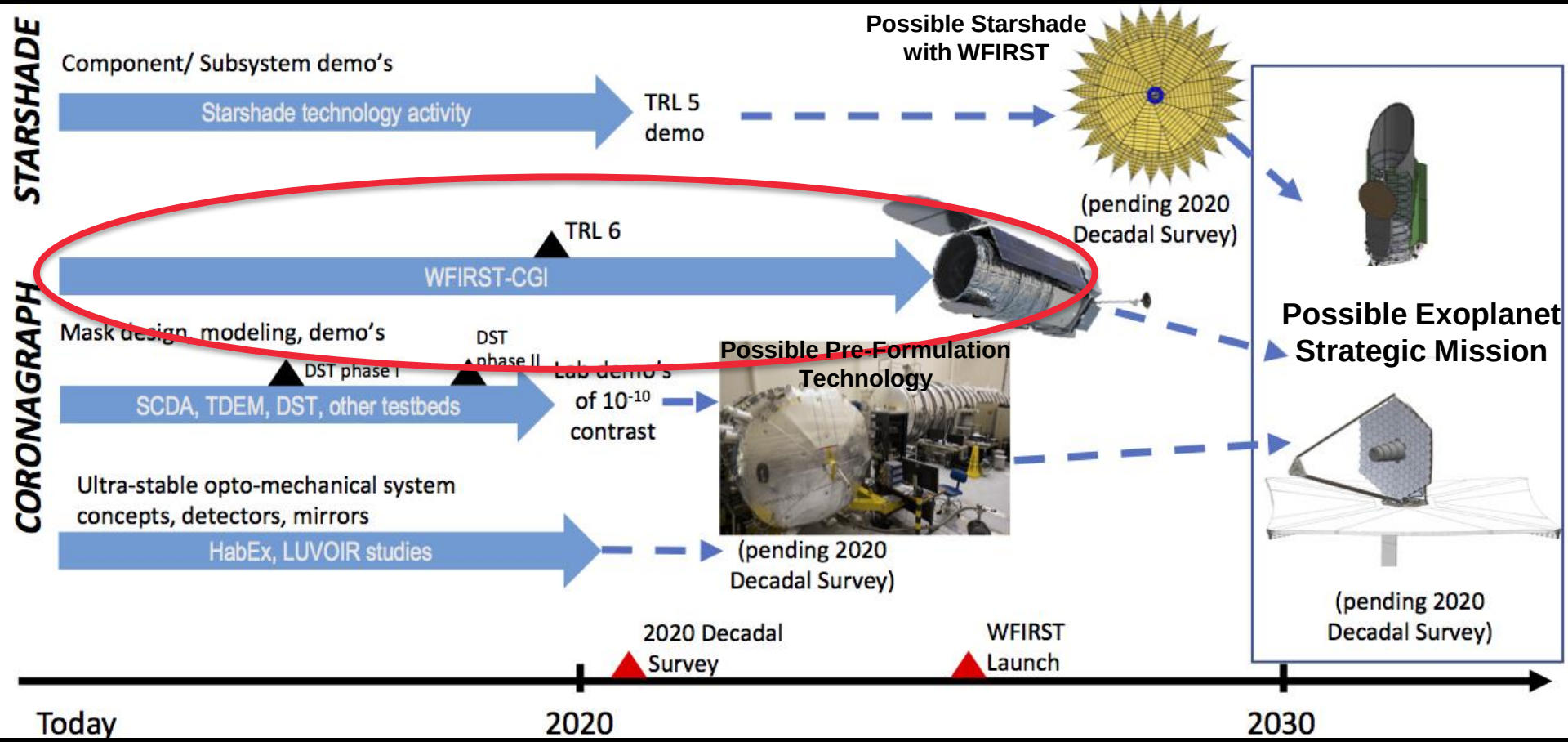


Internal Occulter (Coronagraph)



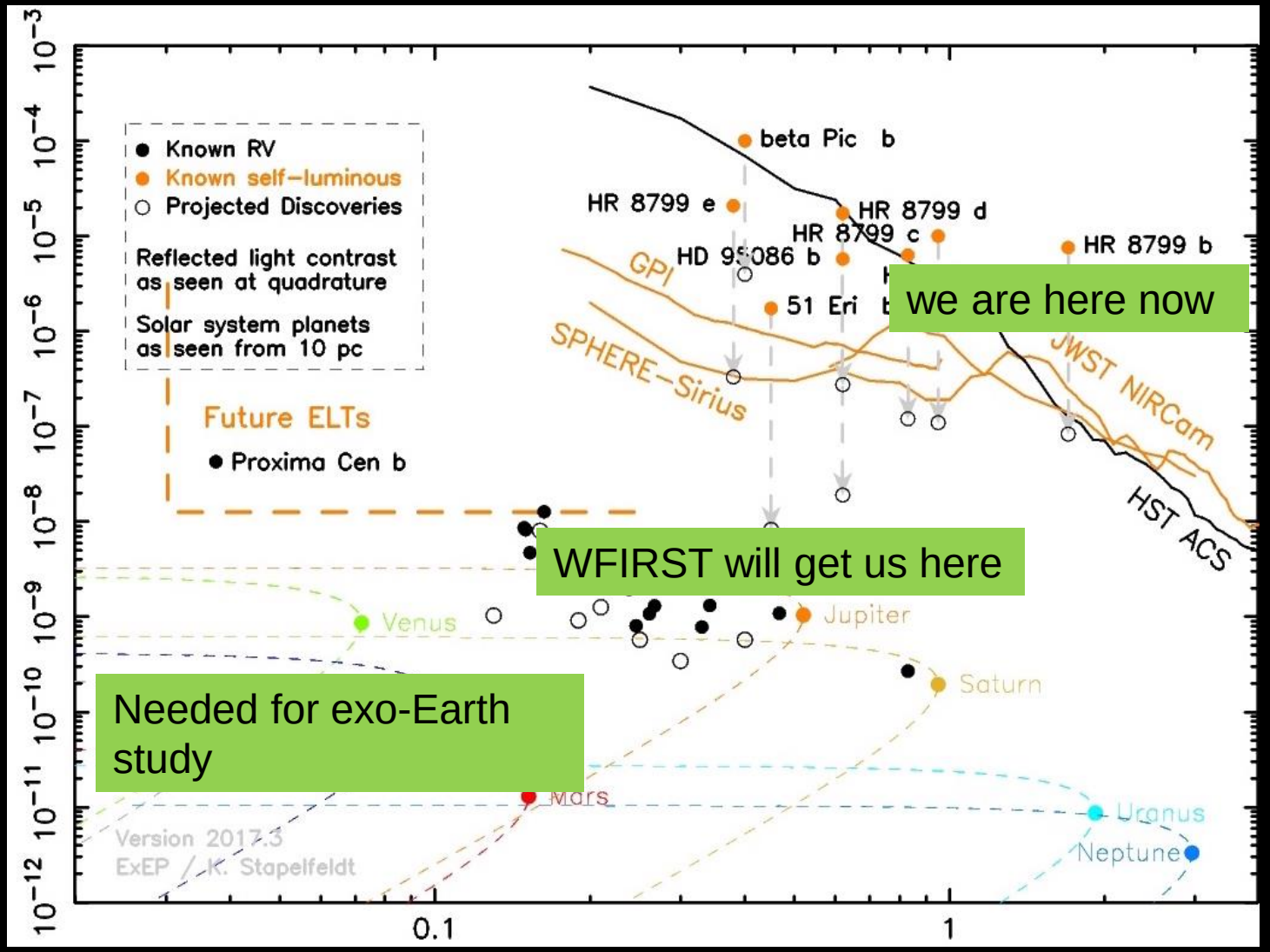

NASA's
Exoplanet
Missions
WFIRST
(mid-2020s)
JWST[2]
(2018)
TESS
(2018)
coronagraph
Kepler
Spitzer
Hubble[1]
coronagraph
First high-contrast coronagraph baselined; starshade compatibility under study
New Worlds Telescope
(mid-2030s)
2020 Decadal Mission Concept Studies
Origins Space Telescope (Far-IR)
Habitable Exoplanet Imaging Mission
Large UV/Optical/IR Surveyor
Lynx (X-ray Surveyor)
Driving science is direct imaging of exo-Earths
[1] NASA/ESA Partnership
[2] NASA/CNES/ESA Partnership
Technology development towards this possible future mission is already underway

Possible Technology Path to Imaging Exo-Earth



WFIRST Coronagraph

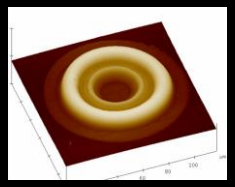
A key stepping stone



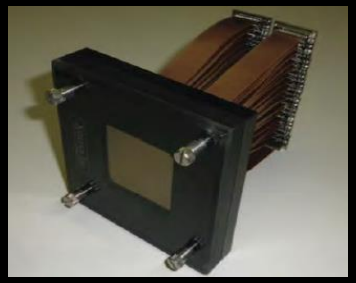
WFIRST Coronagraph Tech Development

Achieved technology milestones to TRL 5

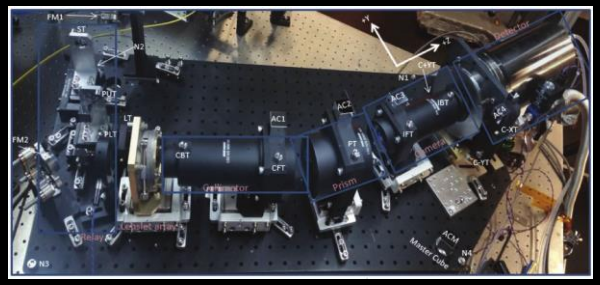
High-contrast coronagraph masks with a highly obscured pupil



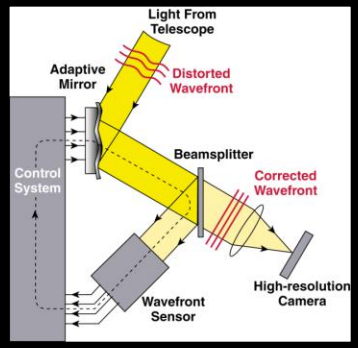
Deformable mirrors



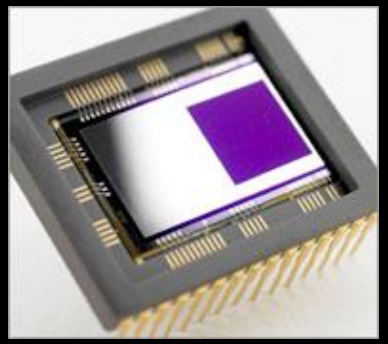
Integral field spectrograph + coronagraph



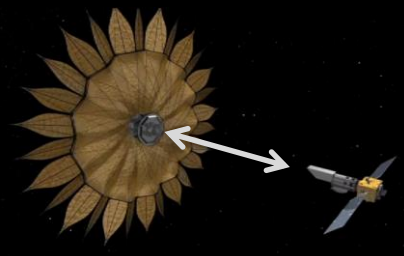
Low order wavefront sense / control



Ultra-low noise EMCCD for space

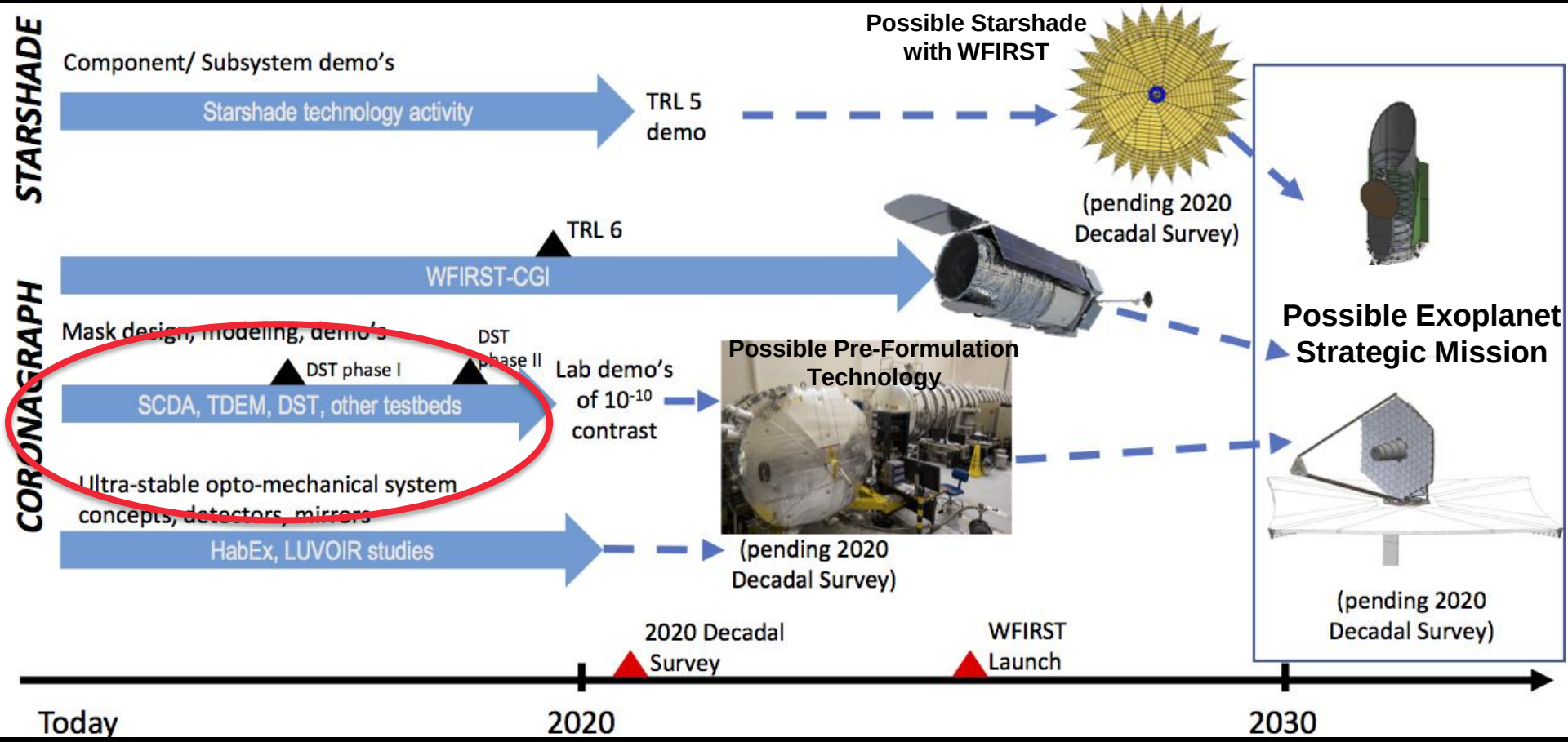


Compatibility with a starshade for possible rendezvous mission pending 2020 Decadal Survey



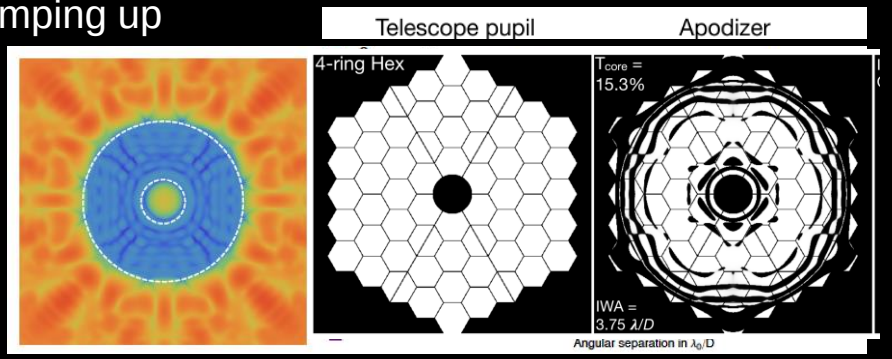
See the three
WFIRST Coronagraph sessions:
Tuesday 8:30 am, 10:40 am, 1:50 pm

Possible Technology Path to Imaging Exo-Earth



Segmented Coronagraph Design & Analysis (SCDA) Study

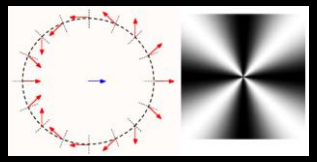
- ExEP-led study to evaluate coronagraph designs for a segmented/obscured telescope
  - Stuart Shaklan (JPL) is Study Lead, five teams
  - 12 m class on-axis telescopes with central obscurations
  - Finite star size
  - Compared to clear apertures
- APLC design so far most successful
  - APLC: Apodized Pupil Lyot Coronagraph is being developed at the STSCI (Soummer)
  - APLC robustness against design tolerances and segment phasing errors being evaluated
  - Vector Vortex being optimized for finite star size and on-axis secondary
  - PIAACMC considered for longer-wavelength use
  - VNC experiencing challenges; HLC ramping up



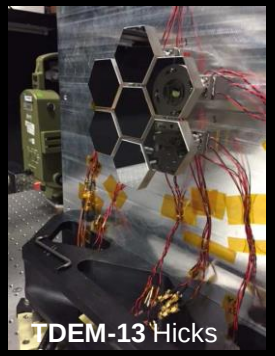
See the Segmented Aperture Coronagraphs Session
Tues 3:40 pm

NASA TDEM Awards

- Annually competed awards solicited to meet NASA's priorities
- Active awards are advancing exoplanet direct-imaging technology and yields
- Coronagraphy
  - Vector Vortex (PI Serabyn/NASA-JPL)
  - Visible Nulling Coronagraph (PI Hicks/NASA-GSFC)
  - Astrometry (PI Bendek/NASA-Ames)
  - Deformable mirrors (PI Bierden/BMC, PI Helmbrecht/Iris AO)
  - Polarization (PI Breckenridge/UA)
- Starshade
  - Re-directed to starshade technology activity

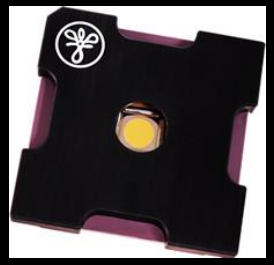


TDEM-14 Serabyn

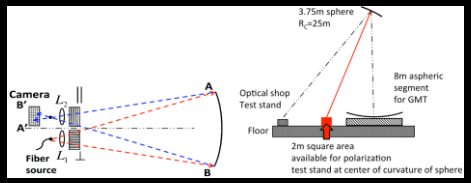


TDEM-13 Hicks

TDEM-13 Bendek



TDEM-10
Helmbrecht

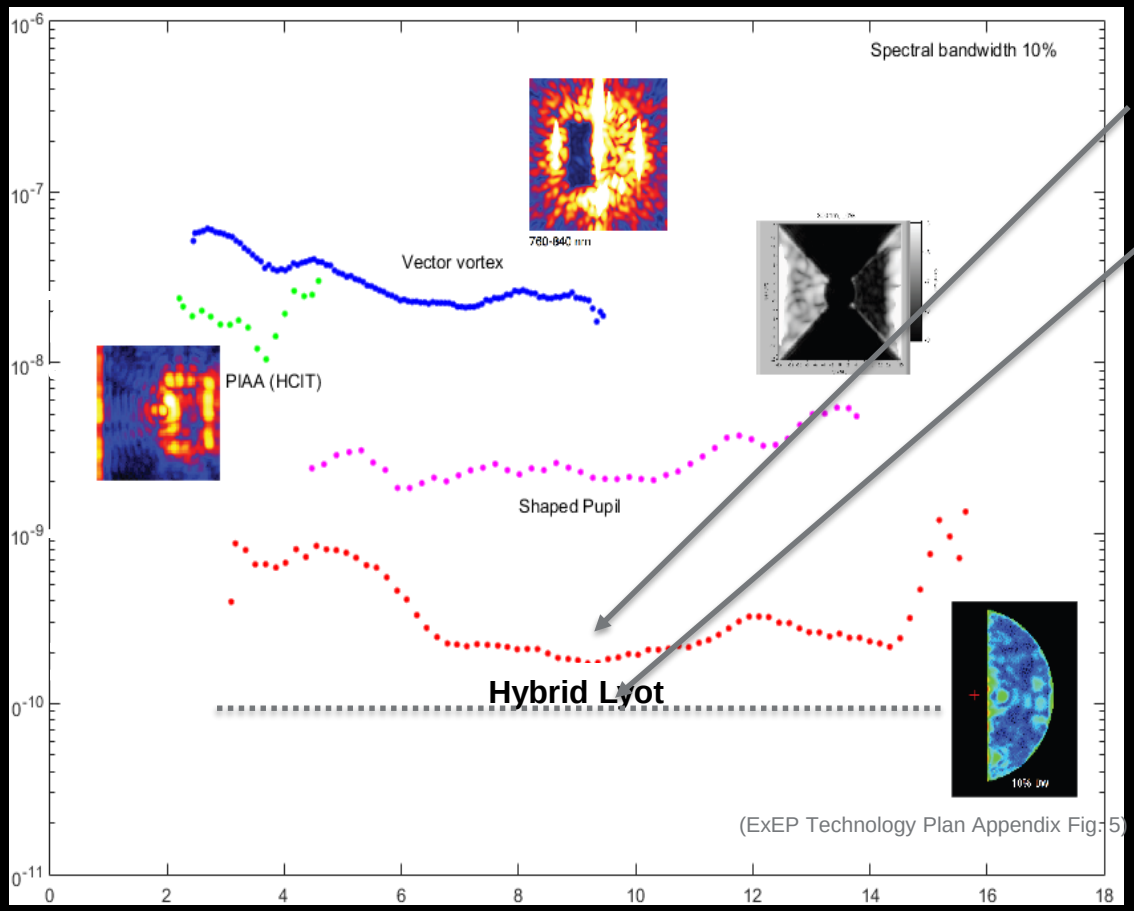


TDEM-15 Breckinridge

TDEM-10 Bierden

High-Contrast Imaging Testbed (HCIT)

Decadal Survey Testbed



Current best contrast demonstration with 10% band (Trauger (JPL)

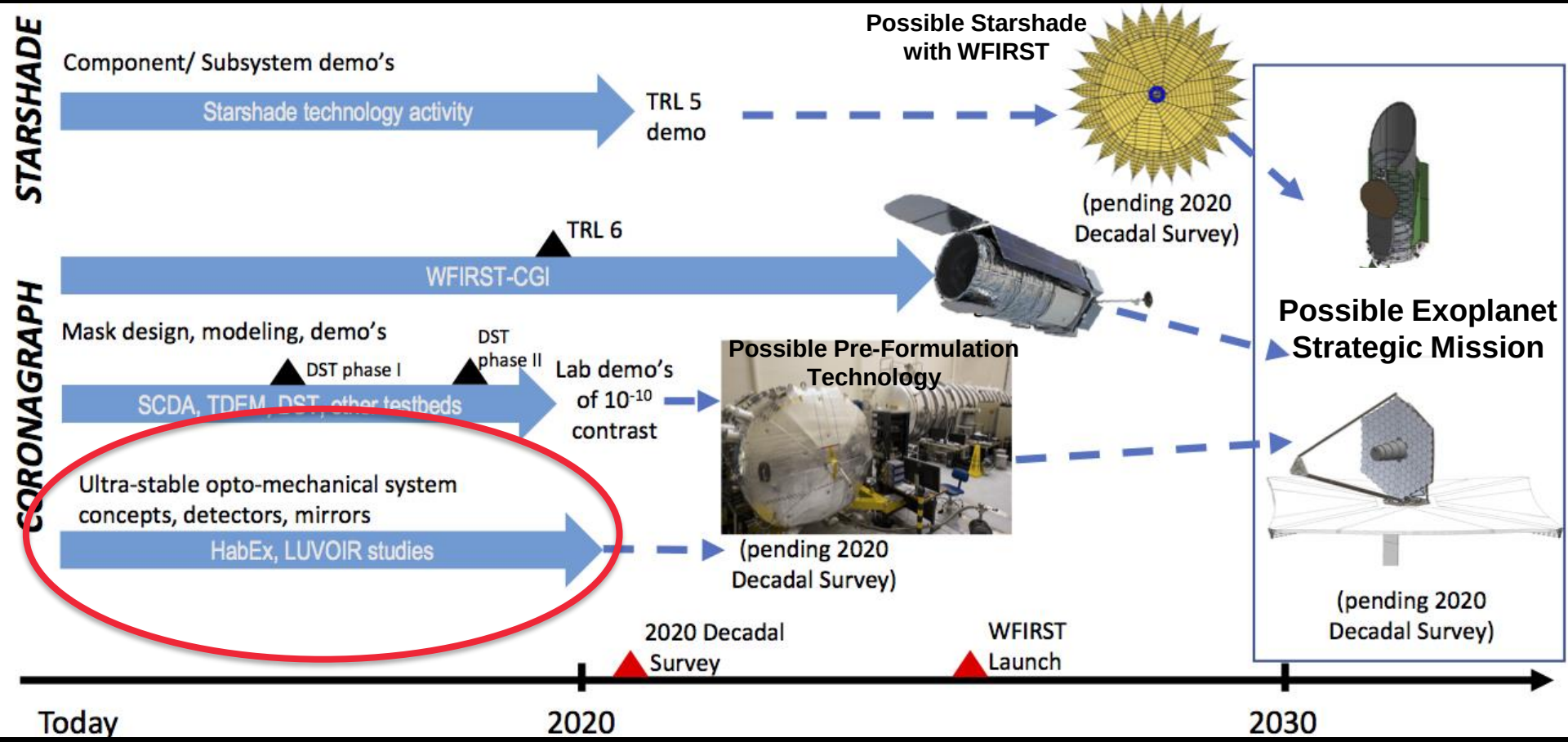
Decadal Survey Testbed

Phase I: meet 10^{-10} contrast with 10% band and a clear aperture in 2018

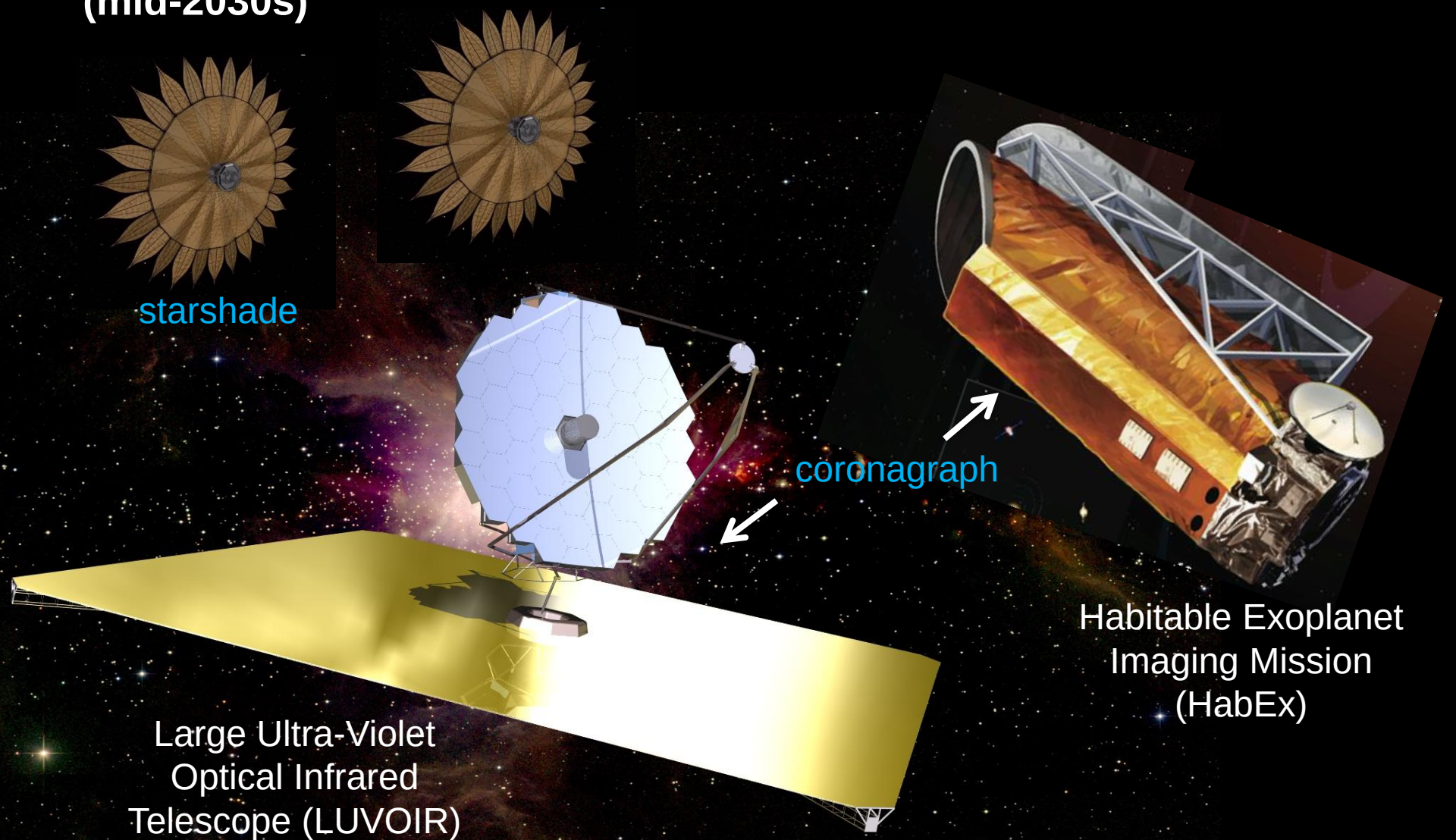
Phase II: replace clear pupil with a segmented/obscured (static) aperture in 2019

Phase III: replace static aperture with a dynamic segmented/obscured telescope simulator in 2020

Possible Technology Path to Imaging Exo-Earth



Possible New Worlds Exoplanet Telescopes
(mid-2030s)



LUVOIR Mission Concept

15m on-axis mirror (120 ~1.5m segments) space telescope using a coronagraph

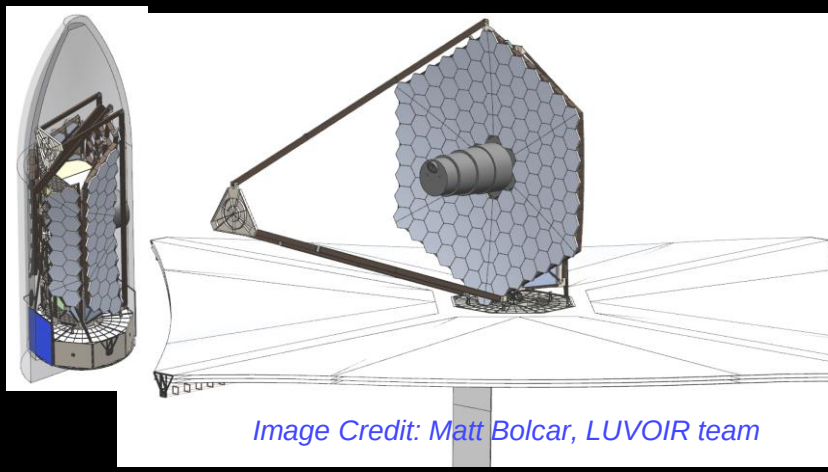


Image Credit: Matt Bolcar, LUVOIR team

Key Technologies:

- An ultra-stable opto-mechanical structure enabling 10 pm rms wavefront stability
  - isolation stages, laser metrology, capacitive edge sensors, thermal control
- Segmented-aperture coronagraphy at 10^{-10} contrast, ≥ 10% band
  - APLC design is the leading candidate – work being done in coordination with SCDA
  - needs to be demonstrated in the lab
- Meter-class segmented mirrors with SFE < 5 nm rms
  - Glass or SiC, high-level of control authority?
- ultra-low noise near-infrared detectors

HabEx Mission Concept

- Off-axis 4 m monolith telescope primary equipped with both a starshade and a coronagraph for starlight suppression

- **Key technologies:**
  - 72 m diameter starshade
    - architecture goes beyond WFIRST rendezvous architecture
  - 4 m glass monolith for space with < 1 nm stability
    - Largest monolith ever flown
  - Microthrusters replacing reaction wheels for fine pointing
    - Successfully flight qualified as part of LISA Pathfinder
  - ultra-low noise near-infrared detectors

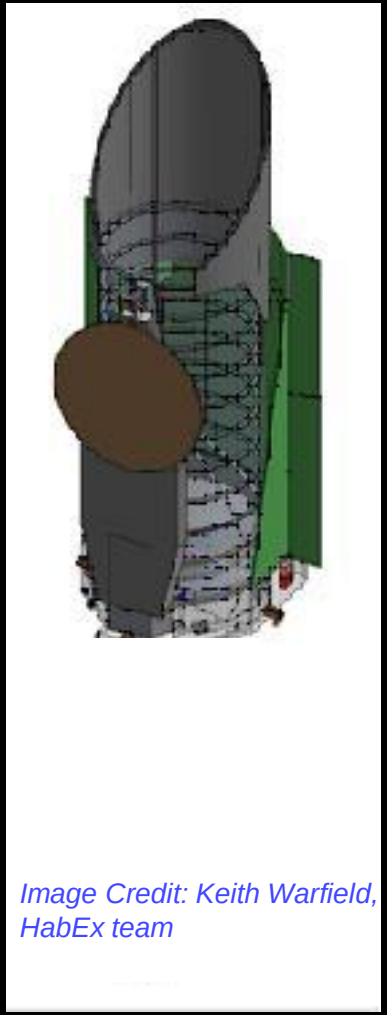
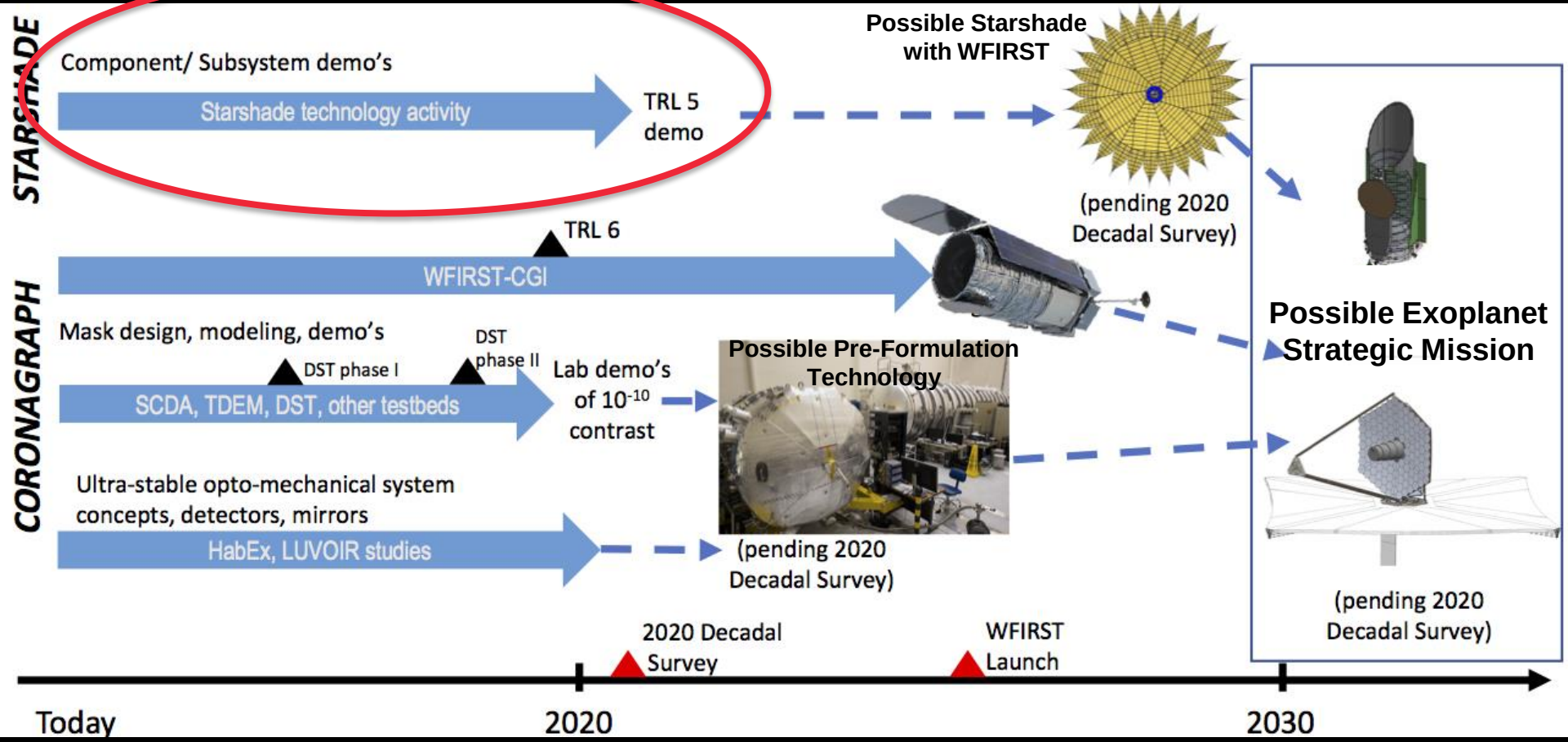


Image Credit: Keith Warfield, HabEx team

Possible Technology Path to Imaging Exo-Earth



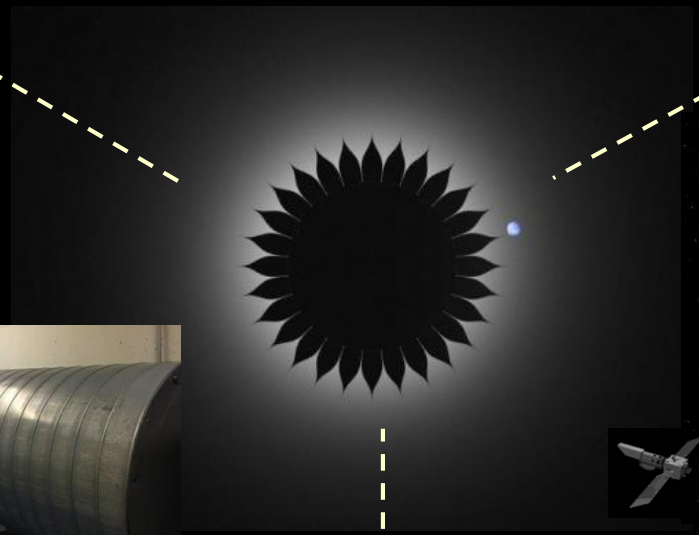
Starshade Technologies

Being Advanced to TRL 5

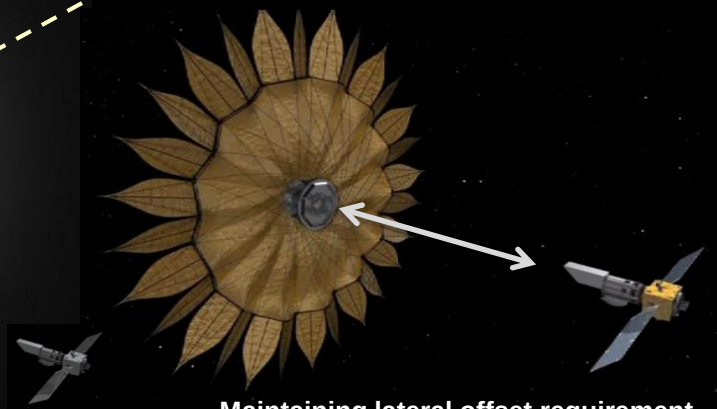
Starlight Suppression

Suppressing scattered light off petal edges from off-axis Sunlight

Suppressing diffracted light from on-axis starlight

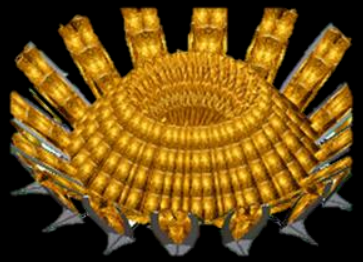


Formation Sensing and Control

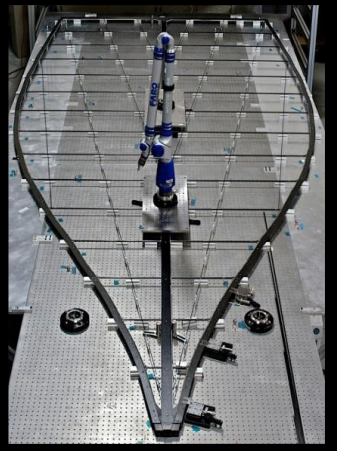


Maintaining lateral offset requirement between the spacecraft

Deployment Accuracy and Shape Stability



Positioning the petals to high accuracy, blocking on-axis starlight, maintaining overall shape on a highly stable structure



Fabricating the petals to high accuracy

Starshade concepts and scaling

HabEx Starshade
4.6 m diameter stowed

WFIRST starshade study

4.6 m diameter stowed

34 m

72 m

LUVOIR Starshade
Pending study
~ 7 m diameter stowed

~ 100 m

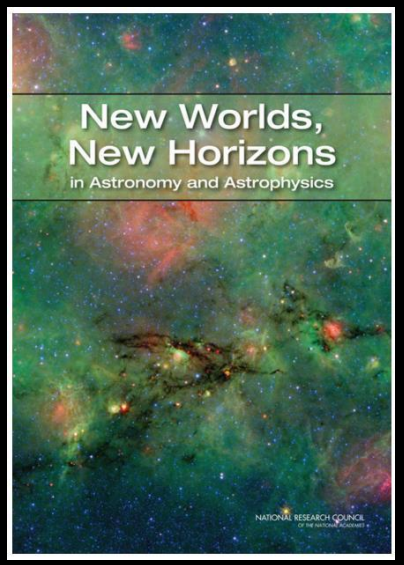
Dependent on scale: deployment architecture, petal manufacture
Less dependent on scale: optical modelling, formation flying sensing, edge scatter

See the
Starshade Session
(Thursday 8 am)

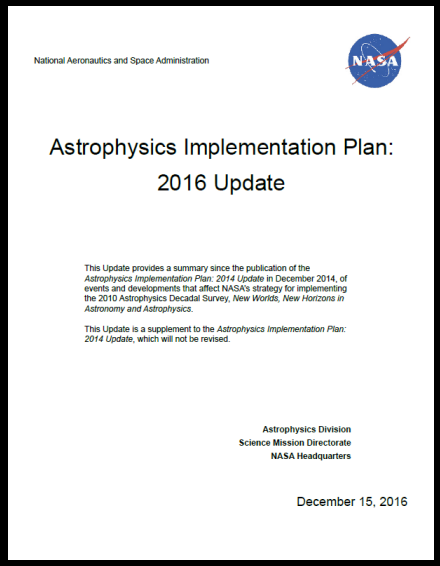
and

In-Space Assembly Session
(Monday 3:40pm)

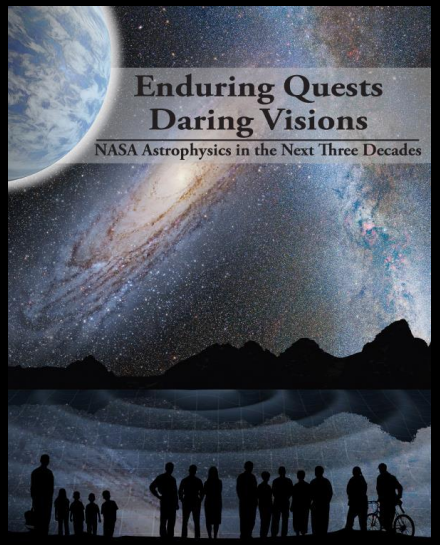
Towards an exo-Earth imaging and characterization mission



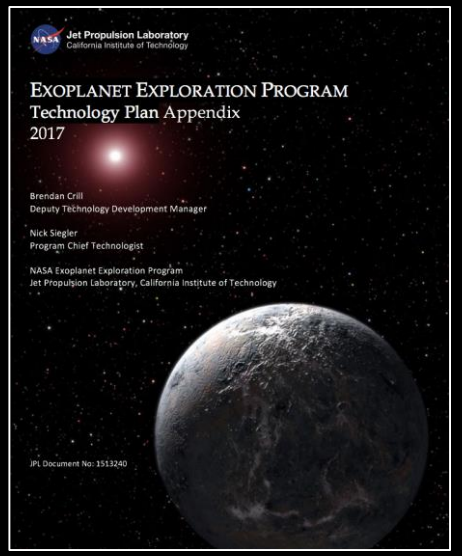
2010 Decadal Survey



APD Implementation Plan (2012, 2014, 2016)



NASA APD 30 year vision (2013)



ExEP Technology Plan Appendix (2017)

- STDT final reports (early 2019)
- 2020 Decadal Survey final report (December 2020)
  - will set the nation's science priorities, including recommendations for NASA astrophysics missions

Acknowledgements

This work was conducted at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration